Challenges in Face Recognition methods: A Review

Master Erasmus Mundus of Science in Vision and Robotics (VIBOT)

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SECTION 1: INTRODUCTION

Recognition system is an identification or verification process that allows detection of true identity. Recognition system based on human traits/characteristic (e.g. iris, face, voice, fingerprint, etc) provides improved security than traditional token based recognition system (e.g ID card, badge, access card, etc) [5].

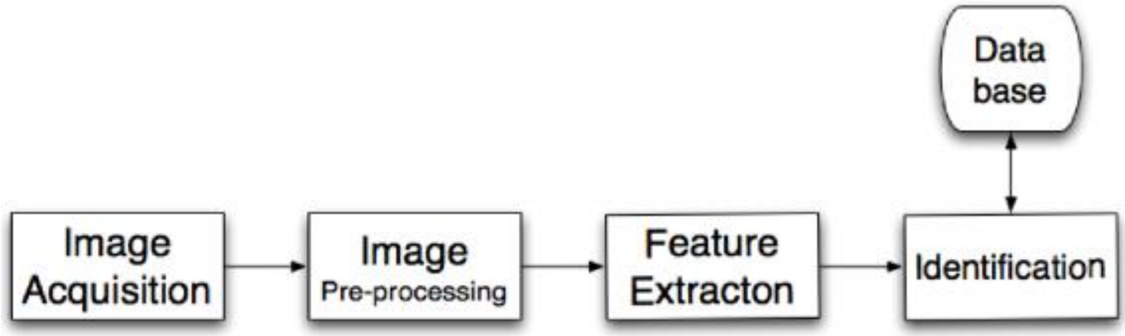

Figure 1: Block diagram of image recognition process

Among the available human characteristics recognition systems, there are several that are not socially acceptable and some are intrusive [5]. For example, fingerprints recognitions are not always socially acceptable because of its association with criminals [5]. Iris pattern recognition is intrusive because acquiring the iris image requires shining a light straight into the eye [5]. Therefore, face recognition is a good compromise in between them [5]. Moreover, face recognition system is contactless, thus it is the most hygienic recognition system.

This review focuses on the challenges in face recognition. Face detection and recognition system consists of several modules which are the same as general image recognition process seen in Fig.1. Image acquisition is a process of obtaining the image and storing in the memory. Pre-processing is a process of preparing the input image to be ready for face recognition. This includes face detection algorithm, which finds the location of the human faces in the image, and other image enhancement techniques, e.g. contrast stretching, noise reducing, sharpening, and so on. Feature extraction is a useful, but not necessary, step for face recognition. Instead of using every pixel in intensity image as a source for comparing the similarity, only major features which are extracted from the image are used. The identification step decides the testing or unseen image as one of the known people in database by comparing either features or pixel intensity.

The major concerns and problems encountered in face recognition systems can be discussed separately in each step of the process. The first concern is in image acquisition step. There are many options for image storing, e.g. image format (2D - 3D intensity array), size (image resolution), number of bit per pixel, and so on. The image storing option should be discussed carefully in order to make a good compromise between the performance and the size of the database. There are many problems in the image pre-processing and feature extraction step because this step tries to extract the human face as well as its features from the input image. This is one of the most difficult task in face recognition especially when there is a variation in illumination, sizes (distance from the camera), or angle (pose) of the faces. Moreover, the presence of facial hair or make up has a great effect to its performance. Noise and occlusion problems also usually occur in the most non-controlled images. The problem in identification step is matching problem. Emotion and aging play have a great effect to the identification process. Finally, the collection of sufficient samples for each face in the database is hard to achieve.

Although there are many problems in the automatic face recognition system, human do this task effortless. Therefore, the paramount goal of the face recognition system is to achieve the same performance as human perception. The following characteristics of human visual perception [1] are the best benchmarks for any face recognition systems.

1. *Image acquisition:* The study [1] shows that internal visual perception of human represents the known faces different from unknown faces. However, there is no evidence about how human internal perception system models the faces, i.e. sizes and resolution.
2. *Pre-processing and Feature extraction (Detection):* There are quite a few problems for human visual perception. When the face is partially occluded, human still perceive the whole face as the missing parts are filled. Human has a very robust detection in severe condition, e.g. changing illumination, the object at the long distance, blurring, and so on. However, there is a strong perception bias toward seeing pattern as a face, e.g. human often see the face pattern in cloud or flame. This is a hysteresis effect, i.e. once human see the face pattern, it is difficult not to see them as one afterward [1].
3. *Identification:* Human uses fewer features with the familiar faces than the non-familiar faces. Also, the familiar faces have less likely to be wrongly recognised. Although human can identify faces rather effortlessly, it is a difficult task to describe human faces. The saliency of the feature in human faces decreases from top to bottom, i.e. eyes pattern is more important than lip or chin shapes.

From the ideal characteristics of human visual perception system, the current automatic face recognition system has general characteristics as follows. However, most of the techniques assume that the human faces are in upright and up front position.

1. *Image acquisition:* Most of the current techniques use 2D intensity images or feature vector (hair colour, eye pattern, etc), or both of them to represent a human faces. There is a study [1] shows that the minimum resolution for automatic face recognition system is 32-by-32 pixel with 4 bits per pixel.
2. *Pre-processing and Feature extraction (Detection):* The detection method based on known a priori characteristic (i.e. faces consist of 2 eyes, nose, and mouth) is commonly used. Some of them use the Hough transform based on constraint method, i.e. faces and eyes have round/oval shape.
3. *Identification:* The automatic face recognition system identifies the name associated with the face. Moreover, the system should be able to identify the same people if there are many instances from the same people in the data set. Matching methods play an important role in this step. The most commonly used method is Euclidean distance. Clustering method is also used to find the degree of similarity of the input image and one in database. Set partitioning method is based on the assumption that there is at least one different feature between each pair of images. Correlation value can be adapted to use with the image as well. Moreover, the combinations of more than one method are widely studied in order to achieve the highest performance.

For the present review the problem of illumination, pose and one sample are analysed and also the different solutions that recent research has achieved.

SECTION 2: GENERAL PROBLEMS

One Sample

In applications such as driver license, passport card identification and law enforcement, there is only one picture available for the face recognition. With this background the goal is to achieve correct identification or verification of a person from the database in any pose, lighting or face expression [2].

The use of only one image per person in the training data set imply different advantages, the first is that only one sample is needed, so, it reduces the intrusiveness that the person is involved in. Secondly there is less laborious effort capturing the training data set, and thirdly, the cost of storing and processing the data set goes to lower levels [2].

Illumination

Most face recognition systems use intensity image as inputs [5]. Intensity image is formed by 2-dimensional array that contains light intensity values per image pixel. Image intensity values depend on the light source/lighting condition at capture time, object reflectance property and the sensitivity of the sensor in image acquisition device. In face recognition system, the captured face is the object and the same face should have the same reflectance property. The image acquisition devices can be manufactured to have approximately uniform sensitivity. Thus, to have minimum variation between images of the same face (or to have positive recognition) the illumination/lighting condition should be constant. However, this condition is hard to achieve in unconstrained environment such as the outdoor.

Varying lighting condition can cause shadowing that accentuate or diminish features of the face [5]. So images of the same face in various lighting conditions can appear significantly different. The problem with illumination arises when the difference between images of the same face in different lighting condition (within class variation) is greater than the difference between images of different faces (between class variation) [5].

Occlusion

Face images contains discriminating features that characterise each individuals. These features are the data used in classification process in face recognition. In the event of occlusion, part of the face is missing from the image, thus only partial features are available for classification [5]. Occlusion might occur due to clothing or accessories worn by the object (e.g. scarf, beard and sunglasses). The absence of key features in the face image might lead to inaccurate classification.

Pose

The pose problem in any face recognition system refers to the capability to recognize face images in different viewpoints. This is one of the main problems and it has been classified in recent surveys [2] [11] as the most unsolved problem in face recognition research.

As it has been mentioned in the introduction, a face recognition system has the advantage of being less intrusive and passive compared to other biometric techniques (iris recognition, fingerprint recognition, etc.). Because of this reason, sometimes only one sample is available in the database. So, it is not always possible to have more than one sample image per face and it can be considered as one sample problem. However since the pose problem is one of the major problems in face recognition, it will be discussed separately in this section.

Suppose that a face recognition system is installed in a train station to recognize terrorists. The faces of terrorists are stored in a database and they are compared with all the traveller's faces in real time. There are two ways to recognize the terrorists: the simple way and the complicated way. Each method has different advantages and disadvantages, as discussed below.

The first one is to collect different poses of each face and compare with the database, which has different poses of each face. In that case the recognition algorithm becomes easier and only the comparison task needs to be implemented. The second one is when there is only one image per terrorist in the database, for example passport photo. In that case, the problem is that the system can only detect terrorists who look directly into the camera. Thus, this solution becomes ineffective. On the other hand, if the pose variance problem is solved, the advantage of face recognition methods being non-intrusive will be achieved. Even with limited amount of features that can be extracted from the person, they can still be recognized.

Table 1 shows different methodologies or different face recognition algorithms in order to know what their basic stages are.

Approach	Face recognition stage			
	Region-based representation	Feature extraction	Dimension Reduction	Classification
Eigenfaces	Holistic	Pixel intensity	Principal component analysis	Nearest neighbour
Fisherfaces	Holistic	Pixel intensity	Linear discriminative analysis	Nearest neighbor
SOM+CN	Evently distributed image patches	Pixel intensity	Self organizing map	Convolutional network
LEM	Holistic	Line edge map	Line segment Hausdorff distance	Nearest neighbor
DCP	Holistic	Local directional corner points	Minimum warping cost	Nearest neighbor
Templete matching	Patches around eyes, nose, and mouth	Pixel intensity	None	Normalized correlation
Modular PCA	Regions around eyes, nose and mouth	Pixel intensity	Principal component analysis	Nearest neighbor
EBGM	Regions around 31 facial component points	Gabor wavelet	Normalized correlation	Averaging
LBP	Evently distributed image patches	Local gradient binary codes	Histogram	Weighted Chi square

Table 1- Face recognition methods and their main stages [11].

In section 3 (pose problem), these methods are analysed further.

Section 3: <u>CURRENT SOLUTIONS</u>

One Sample

There are three groups of methods that try to solve the one sample problem.

<u>The holistic methods.</u>

They are an extension of the principal component analysis (PCA), where each image is represented as a vector with high-dimensional characteristics [2]. On one hand the advantages of using this technique include that the information of texture and shape are preserved. The global aspects of face are also conserved. On the other hand the disadvantages are related to the fact that one sample problem is critic, and as a result that only one vector exists for each class, the variation needed in the different classes cannot be estimated, given as a result that the system fail to work [2].

Using this information, and noting the point that Eigen vectors shows a better performance with a bigger training data, new approaches using this principle have been created to obtain more information from one single image. The principal solution is enlarging the data set obtaining more information of the image based on the principle that humans exhibit similar intraclass variation [2]. For instance the Fisher approach, $(PC)^2$ A that enrich the information of Eigen space perturbing the original image and keeping all the most significant features [3]. Other methods can also include corruption, blurring, noise addition and discoloration of the image [2].

An important branch is using virtual representations of the original image, this includes creating new possible version and novel visual images based on the one sample image. The construction of new representations based on the original image is a partial solution, because it includes a new problem that is to know which representation gives more information that maximizes the performance of the system [2]. Methods as ROCA that generates novel views, it uses geometrical transformations such as rotation, scale and bilaterally symmetric transformation [4]. In the case that mirror images are used, this can also handle the half face occlusion problem [2].

This includes new challenges. Firstly, it does not distinguish different transformation coefficients from different transformations [2]. Secondly, the number of possible novel views tends to infinity. Thirdly, the correspondence of features between the real image and the referenced image should be known to enable the texture rendering [2].

Local Features methods.

The use of geometrical measurements in the picture for instance size of the head, distance between the eyes is a practical approach that solves the problem, but it generates two new problems. The first is the robust and accurate detection of facial features [2]. The second is that the geometrical information is not so accurate and it depends on whether the picture is taken at the same distance and in similar conditions. So a proposed solution is a method that extracts facial characteristics for example *Feature Points* [2].

Identifying and representing each feature allows matching with different faces in two ways, the first is comparing similarities of local features, and the other is related to the global topology similarity of the images. The result permits 94% recognition [2]. But, the problem is that once the topology graph is constructed, it is not possible to create or apply modifications. The solution to this is the use of Gabor wavelet that is robust against illumination changes, distortion and scaling. For example EBGM method uses local and global features. [2] In this case each feature can be scaled and produces elastic matching that result in robustness against appearance changes. Once more, it creates other complications, these are related to the computational cost and that occlusion problem cannot be handled. [2]. The effectiveness of the methods and their performances strongly depends on the accurate localization of the features, but it cannot work with extreme expression changes [2].

Other approach of local features is using the features in an independent form. The advantages include flexibility to recognize a face based on its parts that is given by using each feature separately. This gives as a result the dilemma to know which kind of local features and how to incorporate them to the global information, and the problem in this case is more related to Machine Learning areas [2].

Hybrids methods.

It combines different methods in order to obtain the advantages of each of them, so, in case that one method solves the problem of illumination and other can work with the pose, putting together, the resulting approach is robust against this pair of situations. However it is important to know which and how features should be combined in order to obtain the expected results, and it is reduced to a machine learning issue. The typical method is using virtual samples and local features [2]. In an identification system, other kind of information can be added in order to achieve accurate results, this is including biometric information such as fingerprints, iris and speech [2].

Illumination

The handling of illumination problem in face recognition is still being developed. There have been many approaches in overcoming this problem [ad1]. According to [5], amongst linear face recognition methods, *Linear Discriminant* Analysis (LDA) is superior in handling illumination variation. This might be because LDA looks for the features that best discriminate between different classes [5]. And also LDA is a linear operation which in general is robust to noise and does not have over fitting problem [6]. Study conducted in [7] suggests that hybrid/combinations between different linear methods can improve recognition performance under varying illumination [5], for example, a hybrid between LDA and Singular Value Decomposition (SVD) method [5]. The achieved recognition rate is almost 100% [5]. However, this solution is not effective due to high computational cost [5]. More recent work in handling illumination problem is by 3D modelling of the face [5]. Assuming there are enough data, the model of the face can be reconstructed and face images under various illumination can be synthesised. Thus the query image can be matched against the template image under similar lighting condition. This method can also be applied on pose variation and occlusion problem [5]. The drawback of this method is the high computational cost since the synthesis images at various conditions need to be computed [5].

Occlusion

When dealing with occlusion, most techniques utilises the local approaches [5]. For example, the voting technique where the face is divided into regions and voting space is created to get the best match [5]. This approach is extended to include the probabilistic sense to measure the similarities in each parts of the face (thus taking into account the best local match) in [8]. According to the experiment done in [8] the recognition performance (65% recognition rate) is not affected when 16% of the face is occluded. However, worse result is obtained when the eye area is occluded compared to when the mouth area is occluded [5], as it was mentioned in the introduction that the saliency of features decreases from top to bottom. Another approach is to reconstruct the occluded part of the face by utilising neural network. Study in [9] trains the system with the dataset of non-occluded faces so when the occluded query image comes the occluded part is reconstructed based on the training data before matching is performed. The study claims that accuracy (recognition rate of 79%) is not affected even when up to 30% of the face is occluded [5]. However, since the system utilises nearest neighbour method, retraining is needed each time new instances is enrolled [5]. And in the case of small sample size, the result will be affected [5]. Study in [10] attempted to develop method that can handle both occlusion and illumination variation. It started by extracting key features from the face, then by using dynamic space warping the key features from the query image is aligned and matched against the template. However, this method only works for the case of minor occlusion [5].

Pose

In section two, the pose problem has been introduced and also different methods have been mentioned. Table 2 [11] shows the advantages and disadvantages of these methods related with pose problem.

Approach	Advantages	Disadvantages
Eigen faces	Simple, fast	Sensitive to pixel misalignment, cannot separate image variances caused by identify and pose variation.
Fisher faces	Maximizing the separability of different identities	Sensitive to pixel misalignment, linear classes cannot adequately describe pose variations.
SOM+CN	Fast, tolerance to pixel misalignment due to quantization	Linear mapping cannot adequately describe pose variations.
LEM	Simple, no training and facial component detection required	Sensitive to edge distortions caused by pose variation.
Modular PCA	Simple, fast, local regions around facial components provide some tolerance to pose variations	Sensitive to pixel misalignment in sub-image regions, dependent on facial component direction.
EBGM	Local regions around facial components and Gabor wavelet provide pose tolerance	Slow distortions within local regions were not treated
LBP	Simple, histogram in local regions tolerates pixel misalignment	Image dividing is problematic when pose variation is large.

Table 2- Advantages and disadvantages of general face recognition methods across pose [11]

Local approaches such as EBGM and LBP are more robust to pose variance than holistic methods because they are less dependent to pixel-wised correspondence between gallery and prove images. But in general, these methods only work for small pose variations. The following methods can handle large pose variations.

<u>*2D Methods solutions:*</u>

In [11], 2D techniques to deal with pose problem are classified in three groups: real view-based matching, pose transformation in image space, pose transformation in feature space.

In **real view-based matching** the idea is to get multiple real views of each person as gallery. This means that if one of this systems is installed in an airport, different cameras have to work together in order to get the different real views of the same person. The main problem of this method [12] is that it is generally impractical or unfavourable to collect multiple images in different poses.

Pose transformation in image space tries to produce virtually the previous multiple images in different poses. For [11], Baymer and Poggio [13], are the first researchers to specifically handle pose variations in face recognition. In order to generate virtual views covering a set of possible poses from a single example view they proposed parallel deformation. In [11], the idea of pose transformation in image space is shown in fig 2. Given a probe image and a gallery image, the pose parameter is extracted from the mesh of both images. Then, the mesh of the gallery image is replaced by that of the probe image in order to form a mesh that has the same pose with the input but the same identity information of the gallery image. [14] explains more about the method.

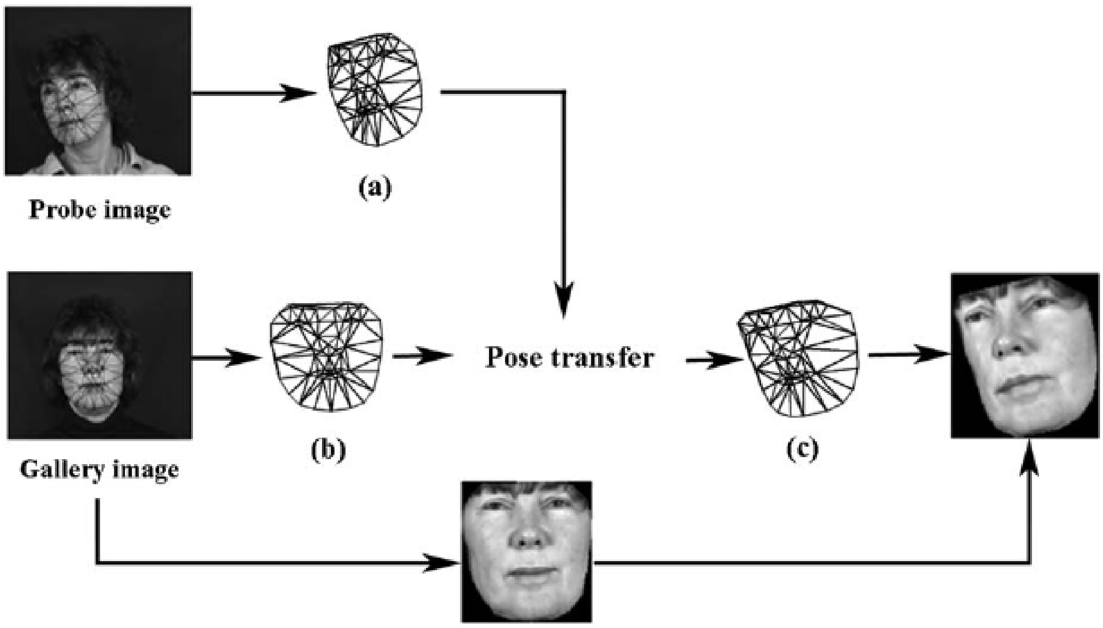

Fig 2- [14]Process of generating virtual face views from training and input images by altering pose parameters and performing 2D image warping.

Finally, **pose transformation in feature space** method tries to transform the image space to a feature space where pose variation can be better tolerated. [11] presents methods that use non-linear mapping defined by various kernel functions, pose specific linear transformation in image space, Gabor coefficients, or frequency domain under Fourier transform.

Table 3 summarizes the advantages and disadvantages of the different methods mentioned in [11].

Approach	Advantages	Disadvantages
Real view matching	Simple, straightforward, good performance	Need to collect a large number of gallery images per person covering all possible poses
Mosaicing	Continuous pose coverage, single panoramic view required	Distortions exist, no vertical in-depth rotation.
Parallel deformation	Simple, fast, sharp, single gallery image	Pose tolerance is small, the choice of reference face is arbitrary
PDM	Simple, fast, single gallery, image, good separation of pose and identity in statistics.	Manual interference, performance largely dependent on PCA training
View-based AAM	Considering both shape and texture, single gallery image, intermediate pose coverage.	Searching is not always reliable, the choice of reference image may introduce identity-related errors.
Linear shape model	Detailed shape description, linking shape variations in different poses	Automatic correspondence is not reliable on non-feature points, many models are required to cover a range of poses.
Eigen light-field	Capable of handling multiple gallery images, single eigen space for different poses	Discarding shape variations by warping which could be critical features for recognition
Pose normalization in AAM	Single AAM for all poses	The choice of reference face shape is arbitrary, the pose normalization assumption is coarse.
Kernel tricks	Non-linear transformation encapsulated in dimension reduction, simple, fast	The existing kernel functions are not specific to pose variations, the choice of kernel functions are limited.
DCCF	Non-linearity by Fourier transform, translation invariant.	Correlation filter cannot adequately describe image variations caused by pose variations.
Linear pose transformation in expert fusion	Simple, characterizing pose variations using explicit transformation.	Linear transformation cannot adequately describe image variations caused by pose variations.
LLR	Localization alleviates inaccuracy of linear approximation of pose transformation	Linear transformation cannot adequately approximate pose variations even in local regions, overlapping of patches may cause problem.
TFA	Consideration of noise factor and offset in linear pose transformation, localization around facial components.	Linear transformation cannot adequately describe image variations caused by pose variations.

Table 3- Summary of the advantages and disadvantages of 2D methods across pose [11].

Section 4: <u>FUTURE DIRECTION</u>

Ideally, a face recognition system should be able to overcome all the stated problems. However, there has not been any developed system that can handle all the problems in face recognition [5]. The identification of features of the face in a robust and accurate form is still immature and is an important and potential area of research. The solution is shared with advances of related areas as pattern recognition, machine learning and machine vision [2].

3D face recognition has the potential to outperform 2D face recognition accuracy and to handle some of the problems like illumination variation, pose and facial expression at the same time [5]. But the problem with 3D face recognition, it is very sensitive towards the data acquisition process [5]. Although face recognition based on 3D algorithm comes with unavoidable huge computation cost [1], the future parallel computation techniques might be able to solve this problem. 3D face recognition system also has the potential in handling occlusion problem. However this research path still has not been explored [5].

Since different method has different strength with respect to different problems, fusion of various recognition methods can potentially improve the performance of face recognition system for any face condition [5]. There is also possibility to improve the performance of recognition systems by developing multimodal system (e.g. combination of face and voice recognition) [5].

Section 5: CONCLUSION

There has not been one developed system that can handle all the problems (one sample problem, illumination variation, occlusion problem, pose variation) in face recognition [5]. In order to solve the one sample problem, some methods need more information to work correctly. The typical form is to create novel images and representations that allows enlargement of the training data set. Local features allow the extraction of information that characterises the image, but it is a problem of machine learning and pattern recognition to handle correctly the different data and select the features that produce the best classifier. The use of different approach of local feature selection solves some specific problems, for instance illumination, expression and pose, but not all of them.

In dealing with illumination variation, linear method such as the LDA seems to work best amongst other methods. The use of hybrid methods collaborate the advantages of different methods, but it is not clear which forms and features that can obtain the highest accuracy and robustness of an identification recognition system. Hybrid between two linear methods is also developed to handle illumination problem and the recognition performance seems to be improved. For handling occlusion problem, various methods have been developed. Approaches based on local features, probability theory/maximum likelihood, face reconstruction and dynamic space warping are some of the current methods to handle occlusion [5]. Face reconstruction can handle the most occlusion which is up to 30% of the face [5]. Solutions for the pose problem are also presented in this review. Real view-based matching is the best solution in 2D methods and allows achievement of results similar to front images. It is not always possible to have a system with more than one camera capturing the same face from different positions. In that case, pose transformation in image space can give a good solution. It allows the creation of virtual images with different views from the original image. But this solution is limited to pose variations of up to 45º.

The inclusion of extra information, for instance biometrics, can produce a more accurate result. Face recognition depends on the other areas of knowledge and their progress, for example machine learning and pattern recognition. Although most methods suffer from high computational cost [5], it can be potentially solved through the development of parallel computing techniques [1]. Since no unique solution to all of the problems has been developed, this is still an active research area.

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